Progress Report

ONR Grant No: N00014-91-J-1299

# DEVELOPMENT OF THE MICROSTRUCTURE BASED STOCHASTIC LIFE PREDICTION MODELS

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SUMMARY

This progress report accounts for the work performed during the first six months of the program and describes plans for the remainder of this calendar year. The project is currently at the end of the initiation stage and all goals set in the proposal for this time period have been accomplished. The program has now all required personnel, equipment and materials to carry the planned research, and work on the characterizations of the 7050-T7451 plate alloys is in progress. The microstructural characterizations which are in progress include measurement of the grain and subgrain sizes, recrystallization levels, identification of all phases and measurement of the volume fractions and spatial distributions of the second phase dispersions and porosities. This measurements will be completed during first quarter of 1992 and the results will be used in the development of preliminary life prediction models for aluminum alloys.

## INTRODUCTION

The purpose of the fatigue life prediction program at UCLA (ONR Grant No. N00014-91-J-1299) is to characterize statistical changes taking place in the microstructure during fatigue of metallic alloys and to develop stochastic life prediction models based on these characterizations. In the three-year Phase I of the program the microstructures and fatigue behaviors of 7050 and 8090 aluminum alloys will be studied. This will be followed by the two-year Phase II during which the life prediction models developed for the aluminum alloys will be generalized to predict fatigue limits in steels and superalloys. During this stage of the program also an expert system for an easy access to all results will be developed.

A detailed time chart for the project can be found in the proposal [1]. It assumes that the first six months of the program will be devoted to the activities associated with the start of the program, initiation of the work on the characterization of the 7050 alloys and development of the image analysis software. This progress report gives account for these first six months and also describes the direction of the program for the remainder of this calendar year.

## PROJECT STATUS

We are happy to report that we have accomplished all goals set in the proposal for the first six months. We have now all necessary personnel, equipment and material to curry out the Phase I of the project. We have started the characterizations of the 7050 alloys and our work on the development of the software for the microstructural characterizations is also on schedule.

### Personnel

In addition to the principal investigator, two more persons, Ms. Annetta J. Luevano and Dr. Jimin Zhang, have been hired in April to work on the project. Both of the newly hired are accomplished electron microscopist; Ms. Luevano specializes in the aluminum-lithium alloys and Dr. Zhang has extensive experience in a variety of metallic and ceramic materials. During 1991 they will be initially working on the grain and subgrain size measurements in 7050 alloys and then on the identification and characterization of the second phase dispersions in the same materials. Their responsibilities will also include development and/or refinement of all quantitative TEM techniques needed in the project. Dr. Zhang will be additionally working of the development of the image analysis software and on the life prediction models.

Dr. Przystupa (PI) will be responsible for the overall supervision of the project and for the formulation of the life prediction models. He will be also working on the implementation of the tessellation programs [1], texture analysis and on the development of the image analysis system.

Equipment

The image analysis system planed for the purchase in 1991 has been already in place. The system consists of the IBM Model 70 computer (with system and word processing software), PC mouse, HP LaserJet IIP printer, HP ScanJet Plus Scanner and a modem. We have also purchased Fortran and C++ compilers which we will be using in our software development work. The computer system will be primarily used for the tessellation analysis, digitizing and storage of the micrographs and for the automation of the measurements of some of the microstructural characteristics. It will be also used in our modeling work either directly or as a terminal to the mainframe computers.

Materials and Testing

On April 11 and 12, 1991 Dr. Przystupa visited Alcoa Technical Center to lay groundwork for Alcoa/UCLA collaborative work on the program. It was agreed during that meeting that Alcoa would manufacture and supply all aluminum alloys required by the program and perform necessary fatigue and mechanical testing. UCLA will be responsible for the material characterizations and selected fatigue crack growth experiments.

The materials which will be investigated during the first year of the program are existing 7050-T7451 commercial thick plate alloys with "high" and "low" porosity levels. Both materials have been extensively tested by Alcoa and their mechanical property and fatigue data are readily available from Alcoa publications. During the second and third year of the program the 8090-like Al-2.5Li-1.3Cu-1Mg-XZr alloys in T8 conditions and with three different grain morphologies will be studied. These alloys will be manufactured by Alcoa and will have (1) fine equiaxed grains, (2) thick pancake grains and (3) thin elongated pancake grain structures.

The following samples of 7050 alloys with both "high" and "low" porosity levels have been selected for the microstructural characterization at UCLA during the first year of the program:

1. Original Plate:
   - surface
   - quarter-section
   - center
2. Fatigue Samples:
   - smooth fatigue failures (35 ksi, R = 0.1)
   - open hole fatigue failures (two stress levels, R = 0.1)

Since the selection includes samples from both the starting materials and specimens after failure, it will be possible to compare original and final "fatigued" microstructures in these alloys. Also, since open hole specimens were tested in two different stress levels it

will be possible to investigate the influence of different stress levels on the evolution of the microstructural characteristic during fatigue.

Results of the microstructural characterizations together with the results of the mechanical testing supplied by Alcoa will form a complete set of data necessary for the formulation the preliminary life prediction models. We plan to have these models ready by the end of this year and test them during first quarter of 1992.

Material Characterizations

We are currently working on the measurements of the grain and subgrain size distributions for the starting 7050 alloys. Ms. Luevano and Dr. Zhang have developed sample preparation procedure specific for our polishing equipment. This procedure is shown schematically in figure 1a; it allows for the resolution of both grain and subgrain boundaries. Figure 1b shows typical grain size structure of the 7050-T7451 plate alloy on three perpendicular cross-sections. The micrographs shows that the alloy is partially recrystallized and allows for the clear distinctions between light, irregular recrystallized grains and darker, pancake shape unrecrystallized grains with subgrain boundaries. We are using linear intercept method to measure average grain sizes and plan to use spherical harmonics to describe directional variation of the intercept lengths and to characterize the distributions of the orientations of grain major and minor axes [2,3]. Since the alloys are partially recrystallized, we will separately measure sizes and shapes of the recrystallized and unrecrystallized grains and also measure sizes of subgrains. We will also determine the degree of recrystallization using point counting method.

We have also developed the TEM sample preparation procedure and the work on the identification and characterization of the second phase dispersions is in progress. The TEM measurements will include estimation of the average volume fractions and spatial distributions of all phases both inside grains and on the grain boundaries. We will concentrate initially on the characterization of the spatial distribution of the grain boundary precipitates. These measurements are the most difficult and we are developing special stereo-imaging technique for this purpose. These measurements will be followed by the estimations of volume fraction and sizes of precipitates inside grains. Finally, the evolution of the dislocation structure and changes of the dislocation densities during fatigue process will be also characterized.

In case of constituent particles and pores we will measure both sizes and coordinates of individual particles and pores. These data will be used in our tessellation programs to obtain local volume fractions, distributions of the distances to the nearest and closest neighbors and in the estimations of clustering indexes for the porosities and constituents.

To automate some of the measurement we are developing an image analysis and enhancement system. We are using HP ScanJet Scanner to digitize the micrographs and to store them on the hard disk in the PCX file format. The stored picture is then manually enhanced and will be used by our programs which will automatically measure some of

the microstructural feature. We are currently working on the program for the automatic measurement of the grain and subgrain sizes. As the next step we plan to automate measurements of particle sizes and volume fractions and then develop a program for the measurement of the characteristics of the fracture surface profiles.

Our existing tessellations and texture (CODF) programs also require extensive modifications. The tessellation programs need new set of graphics subroutines for displaying and printing results using our new computer system. In case of the CODF programs a new pole figure acquisition program specific to the hardware available in our x-ray laboratory has to be developed. The work on the development of this program had to be postponed for the past few months due to the move of our x-ray laboratory to a new location. We plan to finish the work on the modifications of both programs by the end of the summer. Until then we will be relying on the Alcoa Laboratories to perform all ODF analysis.

## Modeling

We are now in the preliminary stages of our modeling efforts. All of the activities up to date centered on the literature survey and evaluation of the microstructure based crack growth and life prediction models proposed during past few years. There are several models of his type in the literature but most of them take only grain size and shape [4-10] or texture [11,17,19] into account and they usually describe behavior of small fatigue cracks [12-16]. We are interested in the models which take all above factors into account and which would also consider influence of the second phase particles and/or voids and orientations of grain boundaries with respect to the moving crack. Up to now we have not found any model of this type.

From all the models which we have reviewed the ones developed by Miller/de los Rios and their co-workers seem to be the most promising [17,18]. Based on their experimental observations of the propagation of fatigue crack in individual grains they have concluded that the propagation of short fatigue cracks is stochastic in nature and that it dependent on the local microstructural variables which are random. They also argue that as crack length increases to several grain diameters, the crack length and macroscopic stress state are the only state variable controlling the crack growth process. In their models Miller and de los Rios took into account texture and grain sizes and also attempted to use Markov chains to predict both fatigue lifes and life expectancy distributions. Although the predictive capabilities of these models are impressive, their application is limited as the models depend on the phenomenological parameters obtained from fatigue experiments rather then on the distributions of the measurable local microstructural characteristics. We plan to use some of the results of the Miller and de los Rios work in our Markov chain/ strongest points models.

Before we proceed to the Markov chain models, and in accord with our plans put forward in the proposal, we will be working on the formulation of the weakest link models. We intend to formulate one empirical model based on the three-parameter Weibull distribution and one phenomenological model base on the randomized crack

growth equation. These models require only basic microstructural and fatigue data as input and will let us rank the importance of the different microstuctural characteristics on fatigue life.

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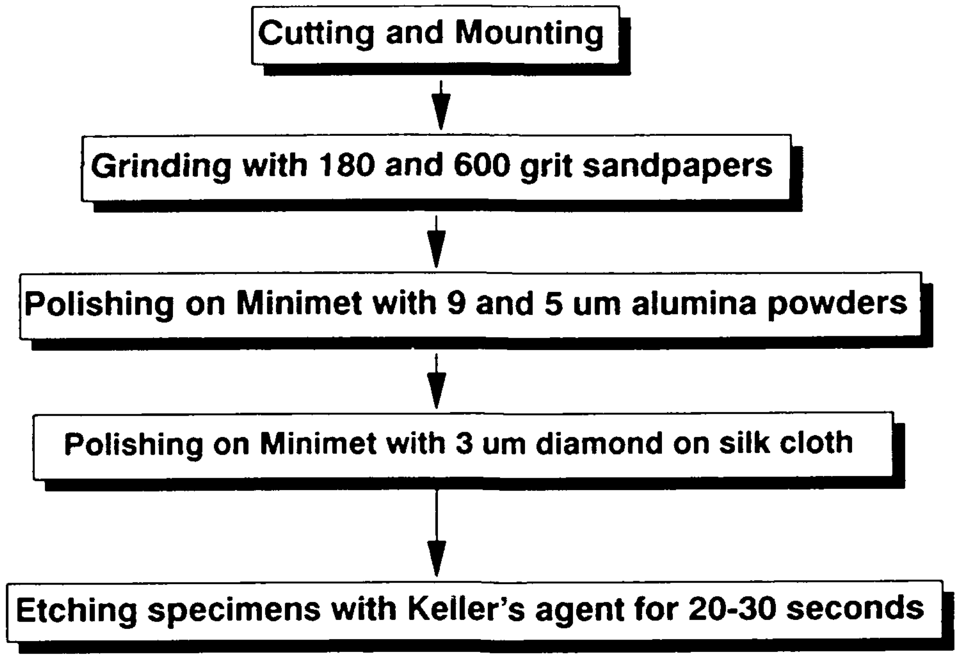
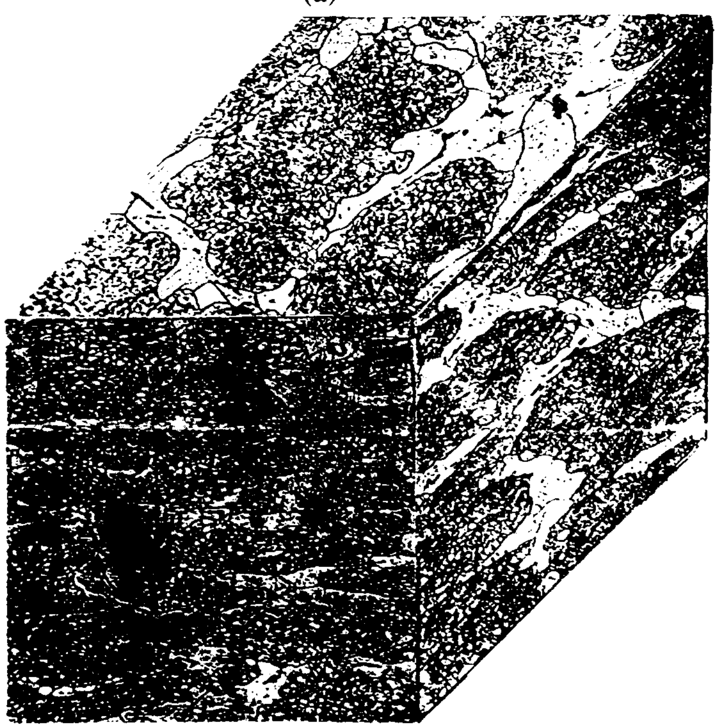



(a)



(b)

Figure 1. a) Schematic diagram of the sample preparation procedure for the grain and subgrain size measurements.

b) Grain structure on the three perpendicular cross-section for the 7050-T7451 plate alloy. Light recrystallized grains and darker unrecrystallized grains with subgrains. Sample taken from the quarter-thickness. (100X, polarized light)